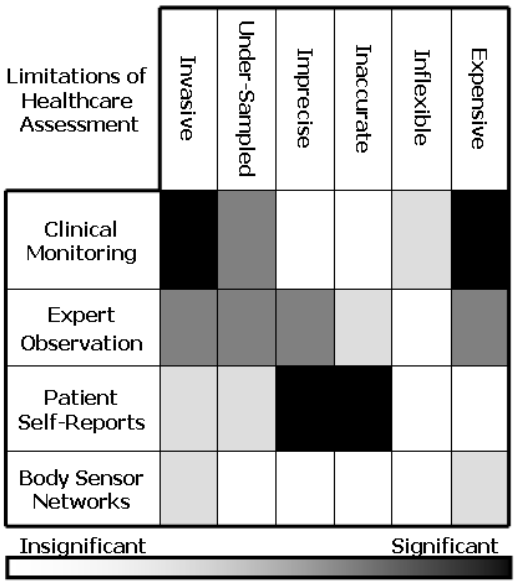
Brainstorms for BASN Paper – Revision 0.3

Ruminations on BASN Utility:

Observation:

- Body-area sensor networks are beginning to find uses in a variety of applications to include: healthcare monitoring, performance assessment, and entertainment.
- Body-area sensor networks provide personalized, accurate, precise, continuous, functionality that is currently unavailable by any other means.



Similar Theme:

- Many cars now have onboard computers that continuously monitor and control systems linked by CAN-bus. Alerts are generated when diagnostics indicate the detection of a fault, which allows the driver or trained professionals to quickly isolate and remediate a problem. Can BASNs become omniscient, omnipresent, and nearly invisible human onboard computer?

Ruminations BASNs vs. WSNs:

WSNs		BASNs
Larger Scale ($\geq 10^3$ m^2, $\geq 10^2$ nodes) w/ emphasis on expandability; Decentralized mesh network with multi-hop routing; In-network aggregation and query processing are key to managing throughput and energy	Network	Smaller Scale (≤ 1 m^2, $\leq$ 10 nodes) w/ emphasis on minimum essentials; Star topology with centralized control
Provided by arbitrarily placed andhigh node density, lower sampling rate ($\leq$ 10 sps)	Fidelity	Provided by specifically placed and low node density, higher sampling rate ($\geq$ 100 sps)
Miniaturization ($\leq$ 25 cm^3) desired for future application; Environment Hardened	Form Factor	Miniaturization ($\leq$ 5 cm^3) essential to current application; Wearable or implantable (biocompatible), and usable
Higher battery capacity ($\geq$ 1000 mAh); Irregular recharge cycle ($\geq$ 1 Year); Solar scavenging potential	Energy (Li-Poly)	Lower battery capacity ($\leq$ 200 mAh); Regular recharge cycle ($\leq$ 24 hours); Mechanical scavenging potential
Largely homogeneous with similar requirements; QoS and graceful degradation ensured by quantity of sensors and efficient data aggregation; Sensor quality less important; Lower signal variability	Sensors (MEMS, et al.)	Largely heterogeneous with different requirements; Sensor quality more important; Higher signal variability
Fixed installation creates lower RF RSS variability; Far-field wireless communication only ($\geq$ 10 m); Interference sources largely known; Low-complexity decoding	Communication (2.4 GHz ZigBee or Bluetooth)	Body shadowing and mobile installation creates higher RF RSS variability; Opportunities for near-field or wired operation ($\leq$ 1 m); Interference sources largely unknown;

essential for aggregation; Security focus		Low complexity encoding essential for less capable nodes; Security and privacy focus
Hardware-agnostic w/ ease of node/system programmability	Operating System	Hardware-aware, highly efficient, and less programmable
Higher resource symmetry; Collaborative processing of sensor group	Signal Processing (MSP430 ≤ 8 MIPS)	Resource asymmetry; Hierarchical processing of single sensor(s); Responsible for QoS and graceful degradation; A key driver of ensuring system energy efficiency
Contract-driven (e.g. government, military, commercial)	Cost (≤ $100 per node)	Consumer-driven (i.e. individuals)

Ruminations on the Need for New Perspective:

Lemma 1:

- Acceptance of discomfort, inconvenience, and invasiveness, or cost incurred by any technology is directly proportional to the value that it provides to the user.

Corollary 1:

- Body-area sensor networks (BASNs) must become nearly imperceptible to the user and affordable, while providing valuable information and/or assistance, to achieve widespread acceptance.

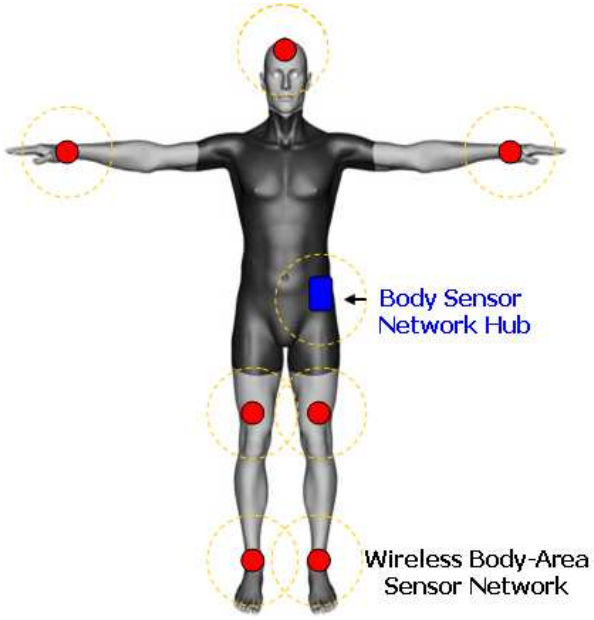
Questions:

- What is considered imperceptible?
  - Ergonomic and small (e.g. wearable or implantable)
    - Effect: Limits energy capacity and resources
    - Effect: Special attention paid to sensor placement to maximize orthogonality of information and minimize obtrusiveness, visibility
- How can we drive cost of BANs down?
  - Volume
    - Effect: Systems that are highly scalable and configurable will meet the needs of many different applications.
- What is valuable information?
  - Fidelic and selective
    - Effect: Higher processing needs consume energy
    - Effect: Processing at the right level of hierarchy to meet the operational profile (e.g. transient detection, longitudinal observation, vigilant monitoring)

Observed Need:

- There is a need to identify and address design considerations, opportunities, and challenges at all levels of design (i.e. circuit to system) to create next-generation BASNs that will achieve widespread acceptance over a wide range of applications.

Ruminations on the Definition of BASNs:



Strict Definition:

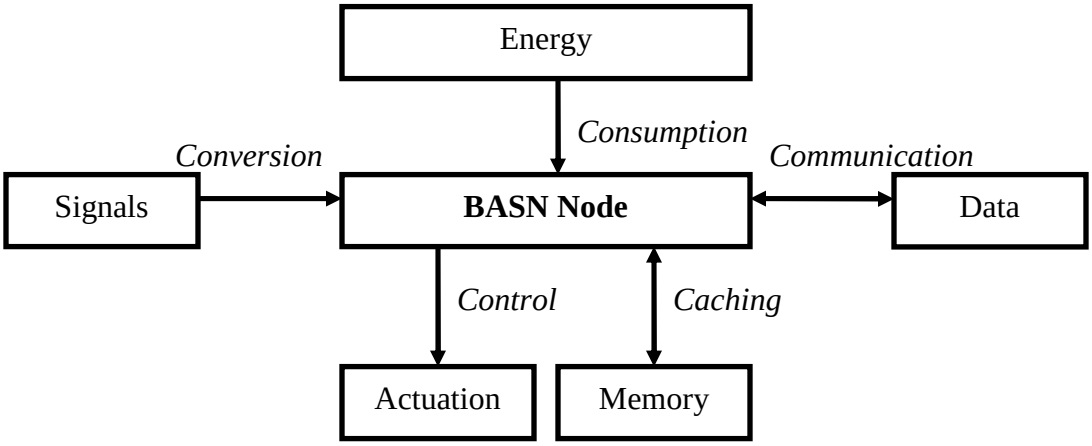
- Two or more interconnected nodes comprising sensing and communication capabilities, located on or within a human body.

Common Characteristics:

- Sense biological, environmental, or physical phenomena using 10 or less sensor nodes
- Have processing capabilities provided by mixed-signal, low-power processors
- Utilize wireless communication to forward relevant information to a super-node (hub), which may be an integration-type device (e.g. Palm or Windows Mobile) with more resources and external communication capability (3G cellular)
- Integrate with larger-scale processing, storage, and presentation software infrastructure

* *See Table Below*

Functional Block Diagram:



Ruminations on the Healthcare Applications:

Sensing Modes:

- Features (Transient Detection)
  - High Sampling Rate Relative to Signal Bandwidth
  - High Resolution
  - Low Processing Demand
  - High Store/Forward Demand
  - Error Sensitive
- Events (Vigilant Monitoring)
  - High Sampling Rate Relative to Signal Bandwidth
  - Variable Resolution
  - High Processing Demand
  - Low Store/Forward Demand
  - Error Insensitive
- Trends (Longitudinal Observation)
  - Low Sampling Rate Relative to Signal Bandwidth
  - Low Resolution
  - Low Processing Demand
  - Low Store/Forward Demand
  - Error Insensitive

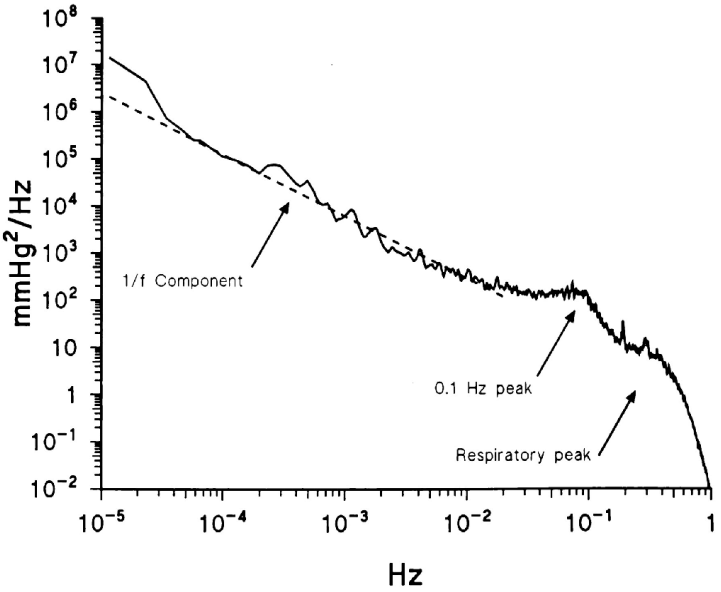
Sensing Options:

- Blood Pressure (Pressure cuff, Intravenous sensor)
  - Data Rate (<1 bps – 1 Kbps)
  - Duration: 1 minute – 1 day
    - Leads: 1
    - Resolution: 8 – 12 bit
    - Sampling Rate: 100+ Hz
- Heart Rhythm (Electrocardiogram)
  - Data Rate (1 Kbps – 100 Kbps)
  - Duration: 1 hour – 1 month
    - Leads: 1 – 12
    - Resolution: 8 – 12 bit
    - Sampling Rate: 250+ Hz
- Respiration (Pressure band)
  - Data Rate (100 bps – 1 Kbps)
  - Duration: 1 hour – 1 day
    - Leads: 1
    - Resolution: 8 – 12 bit
    - Sampling Rate: 20+ Hz
- Brain Activity (Electroencephalogram)
  - Data Rate (10 Kps – 1 Mbps)
  - Duration: <1 hour
    - Leads: 10 – 20
    - Resolution: 12 – 24 bit
    - Sampling Rate: 250+ Hz
- Muscle Activity (Electromyogram)
  - Data Rate (1 kbps – 100 kbps)
  - Duration: <1 hour
    - Leads: 1 – 20
    - Resolution: 12 – 24 bit
    - Sampling Rate: 250+ Hz
- Skin/Basal Temperature (External/Internal Thermistor)
  - Data Rate (<1 bps – 100 bps)
  - Duration: 1 minute – 1 day
    - Leads: 1
    - Resolution: 8 – 12 bit
    - Sampling Rate: 0.01+Hz
- Movement (Accelerometer, Gyroscope)
  - Data Rate (1 kbps – 10 kbps)
  - Duration: <1 hour
    - Leads: 1 – 8 (3 – axis)
    - Resolution: 8 – 12 bit
    - Sampling Rate: 100+ Hz
- Blood Oxygenation (Pulse Oximeter)
  - Data Rate (<1 bps – 100 bps)
  - Duration: 1 hour – 1 day

        - Leads: 1
        - Resolution: 8 – 12 bit
        - Sampling Rate: 0.01+Hz
- Blood Glucose (Subdermal Implant)
    - Data Rate (<1 bps – 100 bps)
    - Duration: 1 minute – 1 month
        - Leads: 1
        - Resolution: 8 – 12 bit
        - Sampling Rate: 0.01+Hz
- Stress (Galvanic Skin Response)
    - Data Rate (1 Kbps – 10 Kbps)
    - Duration: 1 minute – 1 month
        - Leads: 1
        - Resolution: 12 – 24 bit
        - Sampling Rate: 100+Hz
- Biochemical Concentrations (Implantable nano-molecular receptors)
    - ND

Sensed Phenomena:

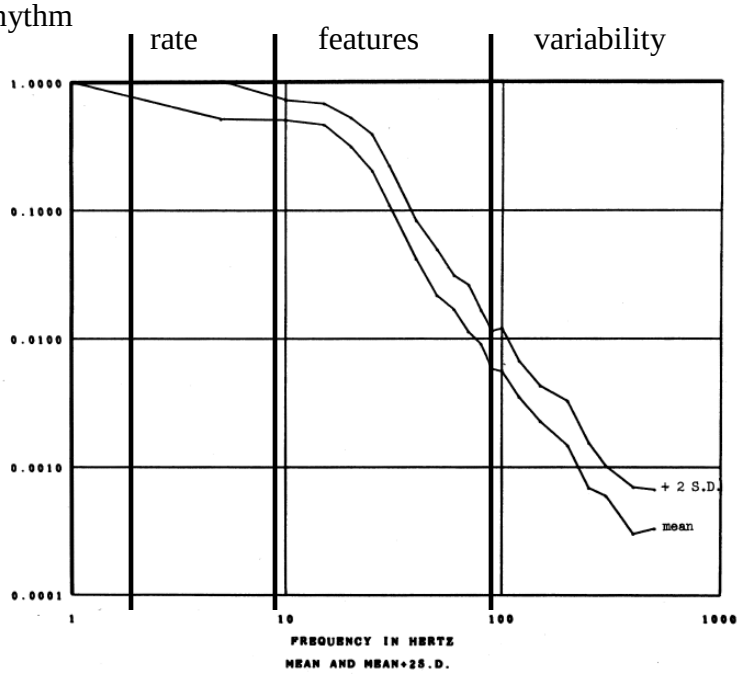
- Blood Pressure



From: Parati et al., "Spectral Analysis of Blood Pressure and Heart Rate Variability in Evaluating Cardiovascular Regulation : A Critical Appraisal," Hypertension, vol. 25, Jun. 1995, pp. 1276-1286.

Critical Care (Transient Detection) Arterial Sampling Frequency: ~100 Hz
Non-Critical (Longitudinal Observation) Oscillometric Sampling Frequency: ~0.01 Hz

- Heart Rhythm

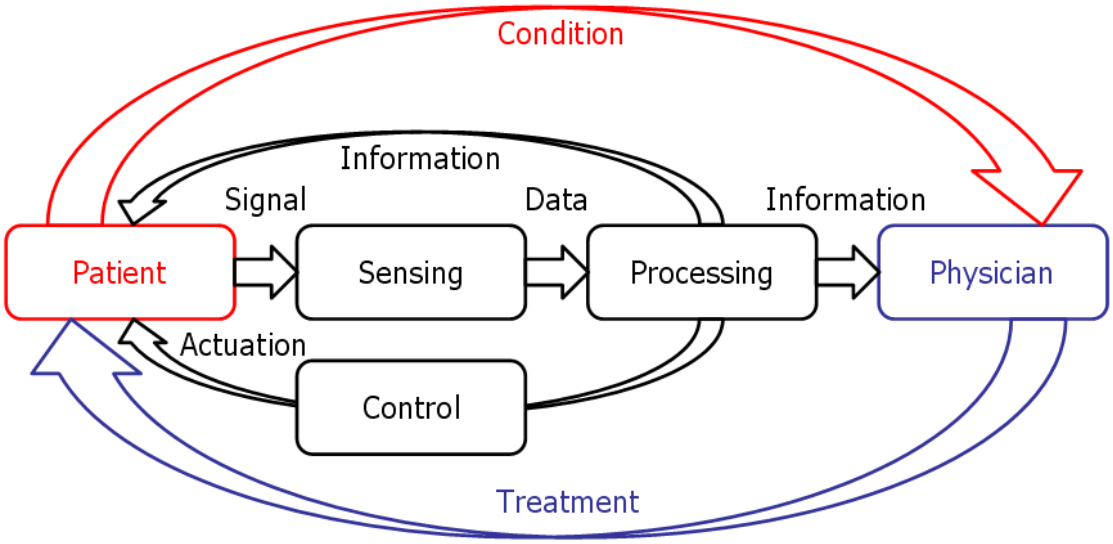


Critical Care (Transient Detection) ECG Sampling Frequency: ~10 kHz

Non-Critical (Longitudinal Observation) Heart Rate Sampling Frequency: 1 kHz

From: D.P. Golden, R.A. Wolthuis, and G.W. Hoffler, "A Spectral Analysis of the Normal Resting Electrocardiogram," Biomedical Engineering, IEEE Transactions on, vol. BME-20, 1973, pp. 366-372.

BASNs in Healthcare:



Take-Away Theme:

- Several stakeholders want information at different times, but the fidelity of desired information is different for the time and the stakeholder.

Ruminations on Table of Characteristics: